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THE NAVAJO COUNTRY

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PART I. PHYSICAL FEATURES*

INTRODUCTION

The Navajo country, rich in historic and scenic interest, is a great mesa-dotted plateau stretching from the Rio Puerco westward to the Painted Desert region of the Little Colorado. Northward its desert wastes extend 140 miles to the San Juan River, where they break down into the picturesque canyon lands of southwestern Colorado (Fig. 1). It is the home of the Navajos, probably the most virile tribe of Indians in North America. It is by contrast the sunset land of the degenerate Hopi. Through it runs the trail of the early Spanish friars who crossed it when it was an unexplored and dangerous region. White settlements are all but wanting outside a few towns near the border. On the geological map of North America published in 1906 a large part of the Navajo country was left blank, for not even the most general outlines had been determined. Until the explorations of the last few years were carried out its canyons and volcanic mesas were virtually unknown to geography and rarely visited by even the trader. Yet its area is three times that of Massachusetts and a transcontinental railroad runs along its southern margin. It is one of the old-new spots of America; it is known about as well to-day as it was in the time of the venturesome padres; but in the long interval between it has remained an almost unexplored wilderness.

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* Figs. 2, 3, 4 and 5 were drawn by Miss Gladys M. Wrigley, Research Assistant on the Society's staff.

In the mind of the native tribes the Navajo country extends from San Francisco Mountain eastward to San Mateo. The northern boundary is an unpopulated zone of variable width, beyond which the Piutes have recognized rights; south of the Zuni Mountains is Apache-land, the home of the Navajo's cousin. That small groups of Hopis are included within his country is a matter of slight interest to the Navajo, since, in his opinion, the pueblos have no rights and their presence is a geographic accident.

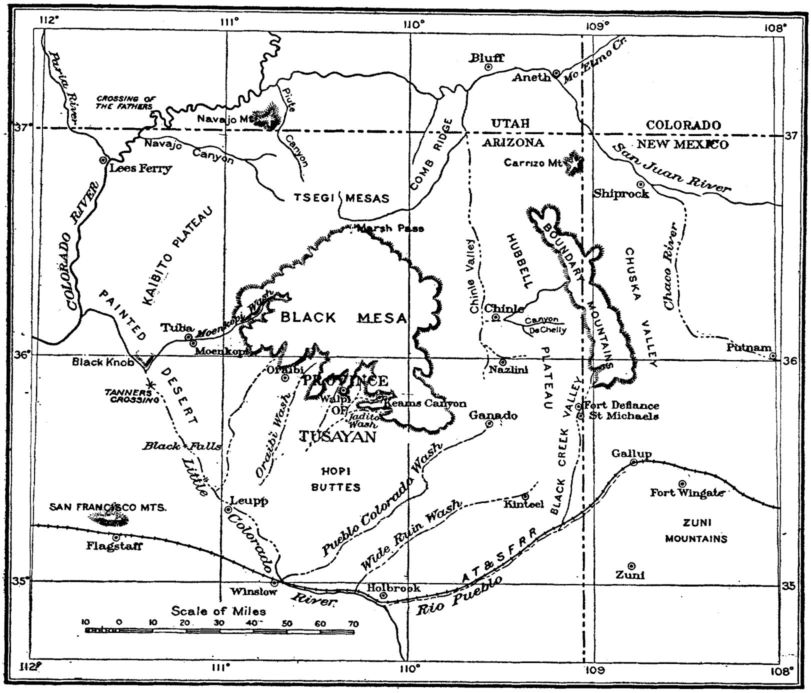

FIG. 1—Outline map of the Navajo country, based on reconnaissance maps of the United States Geological Survey and the United States Land Office, modified and supplemented by recent exploratory surveys. Scale, 1:3,700,000.

N.B.—"Rio Pueblo" should read "Rio Puerco."

The country thus vaguely outlined was made known to the civilized world by Don Pedro de Tovar and Friar Juan de Padilla, members of Coronado's expedition. Setting out from Zuni in July, 1540, these Spanish explorers discovered the Province of Tusayan, the site of the present Hopi villages. During the same summer Don Garcia Lopez de Cardeñas passed through the Hopi villages on his way to the "large river" of which he had heard. After twenty days' travel Cardeñas discovered the Canyon of the Colorado. The exact point from which the river was first seen by white man cannot be determined, since Cardeñas had ample time to reach any spot along the middle Colorado, and the descriptions in the chronicles are applicable to many localities along a hundred-mile stretch of canyon rim. The expedition doubtless followed the ancient Hopi trail leading from Oraibi to the Havasupai villages; the routes indicated by Bancroft and by Winship are impracticable for horses and impossible for foot travelers without transporting a supply of water. The travels of Garces, 1768-1776, were largely through country previously explored by scouts of the Church, but the expedition of Escalante in 1776 crossed the Glen Canyon of the Colorado at the point designated on maps as the "Crossing of the Fathers." If this interpretation be correct, this intrepid priest should be credited with the most daring adventure of all the early explorers, for this route presents most formidable difficulties. The century following the exploits of Garces and Escalante has left little recorded history of Spanish missionary enterprise among the Navajo and Hopi. Only one book published during this period, viz.: Abbe Domenech's two-volume work on the Deserts of North America, need be added to a library of Navajo literature.

Of reports of military expeditions against the Navajos between the years 1845 and 1863, few contain material of geographic value, and all relate to the south and east borders of the reservation. Simpson's report of 1850 is, however, a remarkable book and remains the most complete and most accurate description of any part of the Navajo reservation.[1]

The search for a transcontinental route led to the expeditions of Sitgreaves (1851-52), Whipple (1853-54), and Ives (1857-58), along the line of the present Santa Fe Railroad. Beale's expedition (1858) is interesting chiefly because camels were used for transport. Powell, in 1871, and Howell of the Wheeler Survey (1873) crossed the reservation from Lees Ferry via Moenkopi and Oraibi to Fort Defiance over part of the route previously traversed by Newberry and Ives. On the north border of the reservation Newberry and Macomb (1859), and Holmes, Jackson and Gannett of the Hayden Survey (1875) studied the upper San Juan Valley.

Early exploration of the western portion of the Navajo country resulted from the foresight of the Latter Day Saints. In search of "an opening to preach the gospel," Jacob Hamlin undertook a series of expeditions through Piute and Navajo lands to the Hopi villages. In these explorations not only hostile Indians but the dreaded Colorado Canyon presented serious obstacles. For the years 1858, 1859, 1860, the dangerous "Crossing of the Fathers" (Fig. 1) was utilized. In 1862 a new route was selected crossing the Colorado at the mouth of Grand Wash. The expedition of 1869 crossed the river at the present site of Lees Ferry, the route over which Hamlin conducted Major Powell two years later, and which remains the only route in general use between southern Utah and Arizona. Following a series of disastrous experiments a colony was located by the Mormons in 1878 on the oasis of Tuba, the only permanent settlement ever established between the Little Colorado and the San Juan without the aid of the Government.

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[1] J. H. Simpson: The report of an expedition into the Navajo country in 1849. *Repts. of the Secretary of War, 31st Congress, 1st Session, Ex. Doc. No. 64*, pp. 55-168. Washington, D. C., 1850.

Since the days of the Hayden Survey many archæological reports of a technical character, dealing chiefly with the Hopis and the easily accessible cliff ruins, have been published. Several of these papers have geographic value, and the writings of Mindeleff, of Fewkes and of Prudden in particular are essential to a library of works relating to the Navajo country.

The scarcity of water, the unfriendly attitude of the Indians, and the lack of attention given to the Navajos by the Indian Office, is responsible for the fact that in many respects the geography of the Navajo country is an unworked field. At the beginning of my explorations in 1909, Fort Defiance, Pueblo Bonito, Leupp, Tuba and Shiprock, on the borders of the Navajo Reservation, and Keams Canyon near the Hopi villages, included the Government officials. At that date only one man had succeeded in establishing a trading post north of Black Mesa.

TOPOGRAPHY

In its larger topographic relations the Navajo country is part of the Colorado Plateau Province,—a region of intricately dissected sedimentary strata. About 90 per cent. of its surface lies between the contour lines of 4,000 and 7,000 feet,—the zone of sage and piñon. The extremes of elevation (3,000 feet at the mouth of the Little Colorado and 10,416 feet on Navajo Mountain) permit of wide variation in amount of rainfall and character of vegetation. Broadly speaking, the Navajo and Hopi Reservations constitute a plateau in which the depth of canyons about equals the height of mountains; or, in other words, the downward departures from an uneven surface at 5,500 feet are nearly equal in amount to the upward departures. With the exception of the laccolithic uplifts of Carrizo and Navajo Mountains, the topographic features are those resulting from erosion operating on a gigantic scale. Faults have played no part in controlling the work of streams and the monoclinal folds are of such large dimensions as to interrupt but slightly the general horizontal attitude of the strata. If the Tertiary and Mesozoic strata stripped from underlying beds were restored, a plateau with broadly warped surface, standing at an elevation of about 9,000 feet, would occupy the region along the Arizona-Utah boundary. Great thicknesses of massive sandstone strata alternating with less resistant formations favor the development of lofty flat-topped masses, and many of the highland areas attaining the proportions of mountains are essentially mesas carved from horizontal or slightly tilted strata and bordered by cliffs of commanding proportions. Mesas of the second and third order and innumerable buttes of both sedimentary and igneous materials are characteristic features. Mesa, butte, volcanic neck, canyon, wash, repeated indefinitely are the elements of the Navajo landscape. Rincons, alcoves, towers, columns, windows, arches, and miniature erosion forms of infinite variety and rare beauty stand as ornamental carvings on the larger architectural features. Topographic features of all grades show the influence exerted by aridity. The stream channels are, for the most part, without water, yet enormous accumulations of coarse alluvium, the product of floods, are to be seen on all sides. Talus slopes are in general replaced by bare walls and bed rock is in many places swept clean by winds. The interrupted sheet of wind-blown sand which covers the Navajo Reservation thickens in places to form dunes, traveling with the prevailing southwest wind.

Vegetation, which forms a more or less continuous mantle at higher elevations, is insignificant in amount below 5,000 feet, where desert conditions prevail. These low-lying areas are, however, singularly attractive. Both sand and rock are brilliantly colored; the land is a "painted desert." The gray tones of other regions are replaced by reds and browns, yellows and greens and blacks in masses miles in extent, or mingled to form the "variegated shales" of the early explorers.

Major Topographic Features. The Navajo country is too large and too diversified an area to treat as a geographic unit. Only in a broad sense are the various portions of the reservation alike. It has therefore been found advisable to establish geographic subprovinces on the basis of topography, vegetation, water supply, and other factors which have influenced the manner of life of the native and immigrant population. Twenty-two provinces thus outlined are

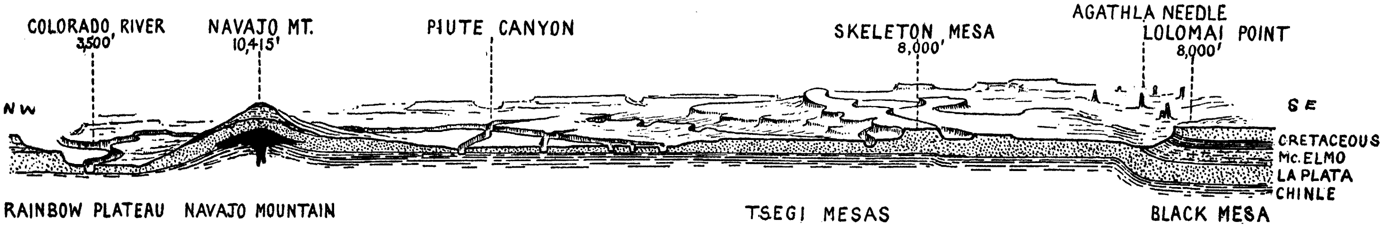

FIG. 2—Diagrammatic section, extending southeastward from the junction of the San Juan and Colorado Rivers to the north rim of Black Mesa. Navajo Mountain, the highest summit in the Navajo country, is a laccolith from which the cover of sedimentary rocks has not been removed. The Piute and other streams of Rainbow Plateau and Tsegi Mesas provinces are deeply intrenched in nearly vertically walled canyons. In the Skeleton Mesa region are numerous cliff ruins, many of them unexplored. Agathla and neighboring spires are volcanic necks.

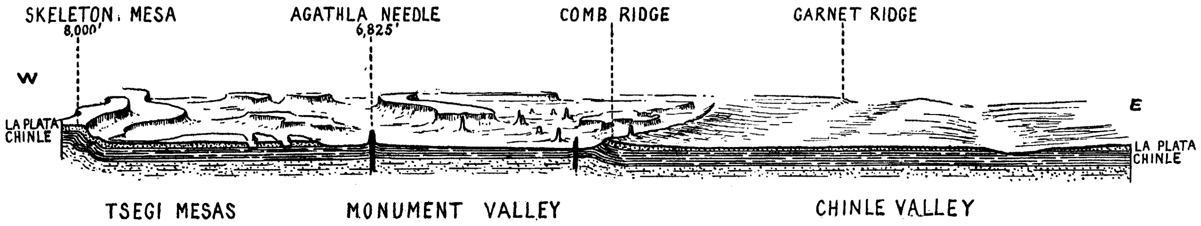

FIG. 3—Diagrammatic section on a west-east line through Agathla Needle. The descent from Skeleton Mesa is accomplished by a series of steps in a compound monoclinal fold. Monument Valley, bounded by the toothed cuesta of Comb Ridge, receives its name from erosion remnants both igneous and sedimentary. Garnet Ridge is the American source of jewel garnets (pyrope), popularly known as "Arizona rubies."

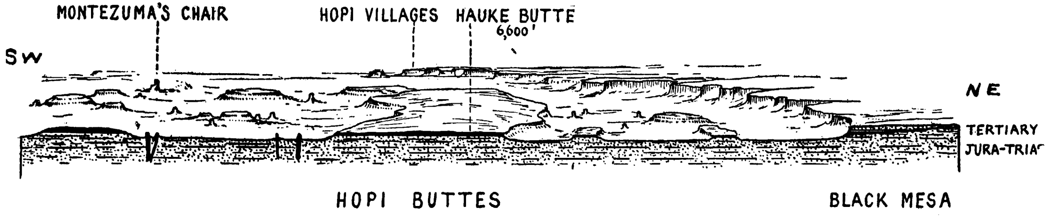

FIG. 4—Diagrammatic section, Oraibi Wash to the southeastern edge of Black Mesa. Montezuma's Chair and other buttes in the foreground, including Hauke Mesa, are volcanic necks and lava-capped buttes. In the mouths of canyons issuing from the rim of Black Mesa are cornfields and ruins. The present Hopi villages, seven in number, are perched on three capes extending southward into a sea of desert sands.

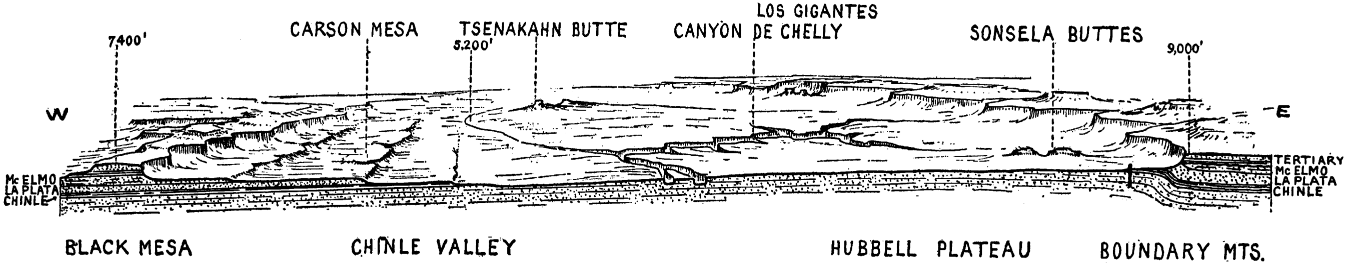

FIG. 5—Diagrammatic section across Chinle valley. The steps leading from Black Mesa eastward correspond in height with the thickness of the Jura-Trias formations. The vertically walled Canyon de Chelly, famous for its cliff ruins, traverses the crest of a low anticline which has given rise to Hubbell Plateau. Sonsela Buttes are volcanic. The Boundary Mountains, capped by Tertiary sediments and lavas, form the eastern limb of a great upwarp, of which Black Mesa is the western margin

discussed in a report to the Geological Survey. For the purpose in hand the accompanying series of diagrams have been designed to bring into relief the major topographic features of the region. (Figs. 2-5.)

Minor Topographic Features. Topographic features resulting from erosion by wind and water are too varied to justify detailed description. A few selected views will, however, aid in filling in the outlines presented in the general topographic sections (Figs. 8-14).

CLIMATE

Without presenting tables of meteorological records, the climate of the Navajo country may be summarized by the following general statements:

The Navajo Reservation is outside the path of frequent cyclonic storms; and the progressive alternations between high and low barometer, warm and cold "spells," wet and dry periods, which characterize the climate of most other portions of the United States are absent. There is a difference of about 3° of latitude between the southern and the northern edges of the area, but the influence of this factor is so completely nullified by topography that Hite (37°50′ N.) is warmer and dryer than Holbrook (34°55′ N.). Topography, in fact, may be considered the primary factor in the climate of the Navajo country. Fort Defiance, elevation 6,900± feet, is colder and wetter than Holbrook, Tuba, and Aneth, 2,000 feet lower. In the Little Colorado Valley group of meteorological stations, Flagstaff (elevation 6,907 feet) has a rainfall of 23.87 inches and a mean annual temperature of 44.7°; Holbrook, elevation 5,069 feet, has 9.16 inches of rain, and a mean annual temperature of 54.2°; and Winslow, elevation 4,853 feet, follows with an annual rainfall of about 7 inches and a mean annual temperature of over 55°. A snowfall of 2 inches per year is normal for Holbrook; the corresponding figure for St. Michaels, elevation 6,900 feet, is 46.1 inches. At elevations on the reservation above 7,000 feet, snow may fall at any time between October 1 and June 1, and may remain on the ground for days or even weeks. My Indian guide says that snow, in some years, lies on Navajo Mountain (10,416 feet) well into July, and San Francisco Peak (12,611 feet) retains its snow in protected places throughout the year. Temperatures associated with elevation determine the length of the growing season and outline, therefore, the areas of land adapted to various crops. The higher lands are too cold for corn and, beginning with 7,000 feet, agriculture must be adjusted to a growing season varying from 89 days at St. Michaels (elevation 6,900 feet) to 143 days at Tuba, and 201 days at Hite on the floor of the Colorado Canyon in Utah. The general effect of elevation is greatly modified by secondary topographic features. The climate of the floor of a canyon may be quite unlike that of the canyon rim. Peaches thrive on the floor of Canyon de Chelly, while the climate of the plateau above is unfavorable for corn, and the cliff dwellers long ago learned that one canyon wall offers favorable locations for homes not afforded by the opposite side.

The rainfall of the Navajo country is characterized by extreme variability in annual, seasonal, monthly and daily means. As shown in the chart (Fig. 6) for Fort Defiance-Fort Wingate-St. Michaels, three stations whose location, elevation and topographic position are so closely similar as to justify treatment as a single station, the annual variation is abrupt and of wide amplitude. The monthly records (Fig. 7) reveal the presence of a rainy season in July and August. Following a period of extreme dryness during which no rain at all may fall, the summer rains become the factor of commanding importance in the Navajo climate. Their presence insures a crop of corn; their absence involves a serious depletion of the native food supply. The meteorological records show that less than 1 inch of rain falls during July, 6 years out of 18 at Fort Defiance; 4 out of 10 at Keams Canyon, near the Hopi villages; 11 out of 13 at Tuba; and 5 out of 22 at Holbrook in the Little Colorado Valley. Clear skies prevail in this region. Flagstaff, 40 miles west of the reservation line, receives 81 per cent. of the possible amount of sunshine; and it has been estimated by the U. S. Weather Bureau

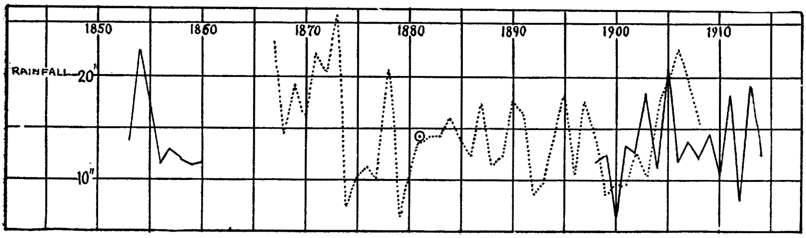

FIG. 6—Mean annual rainfall, Navajo Reservation. Table constructed by combining records by Army officers with those of volunteer observers reporting to the Weather Bureau. Figures for 1853-1860, 1881, and for 1898 to 1904 inclusive, are for Fort Defiance. In 1905 the Fort Defiance rain-gauge was removed to St. Michaels. The records for 1867-1908, indicated by dotted lines in the diagram, were taken at Fort Wingate. St. Michaels is eight miles south and Fort Wingate thirty-seven miles southeast of Fort Defiance. The elevation of these three stations, approximately 6,850, 6,900 and 6,990 feet respectively, and their topographic position are closely similar.

that northern Arizona as a whole has, on an average, 210 clear, 85 partly cloudy, and 70 cloudy days in the year. During May, June, October and November the skies may be cloudless for 5 to 15 days in succession. On the other hand, rain clouds may gather any day during late summer. During August, 1911, showers between 11 and 1 o'clock with a precipitation of from 0.01 to 0.20 inches, were experienced 22 days in succession.

The characteristic storm of the Navajo Reservation is the thunder shower of extreme violence and lasting usually less than an hour. Gentle rains lasting for more than 24 hours are of very rare occurrence. Only one such was experienced during my four seasons' work. The area covered by the shower is frequently only a few square miles, and on two occasions showers of 20-30 minutes duration resulted in wetting less than 300 acres. Many of the storms result in a heavy downpour and the total precipitation for a month is not infrequently the result of a single shower. During hot summer days masses of storm clouds gather, and rain descends without, however, reaching the ground; and on one occasion the only result of a violent thunderstorm which filled the upper air with water was a handful of hailstones dropped into camp. Generally, the intense heat preceding a shower is reëstablished within an hour or two after the rain has ceased, especially at elevations below 6,000 feet. So quickly is clothing dried after one of these showers that it was found unnecessary to carry tents even during the rainy season.

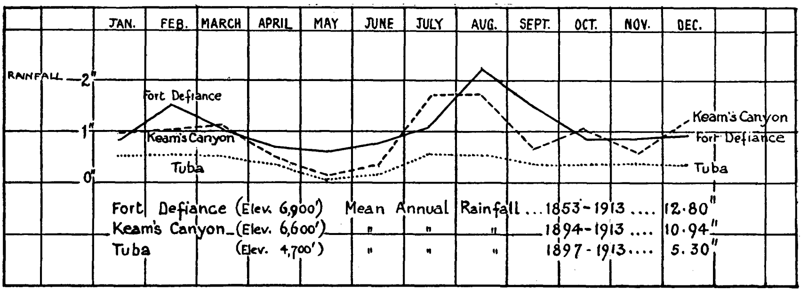

FIG. 7—Diagrams of mean monthly rainfall at Fort Defiance, Keams Canyon, and Tuba.

Lightning is the almost invariable accompaniment of summer showers and constitutes a real danger to travel. During 1911, six Indians were killed by lightning and on two occasions my camp equipage was hit by a bolt. Lightning ranks first as a cause of forest fires in this region,[2] and partly burned trees are everyday sights in the highland forests.

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[2] F. G. Plummer: Lightning in Relation to Forest Fires, *U. S. Forest Service Bull. 3*, 1912. 39 pp.

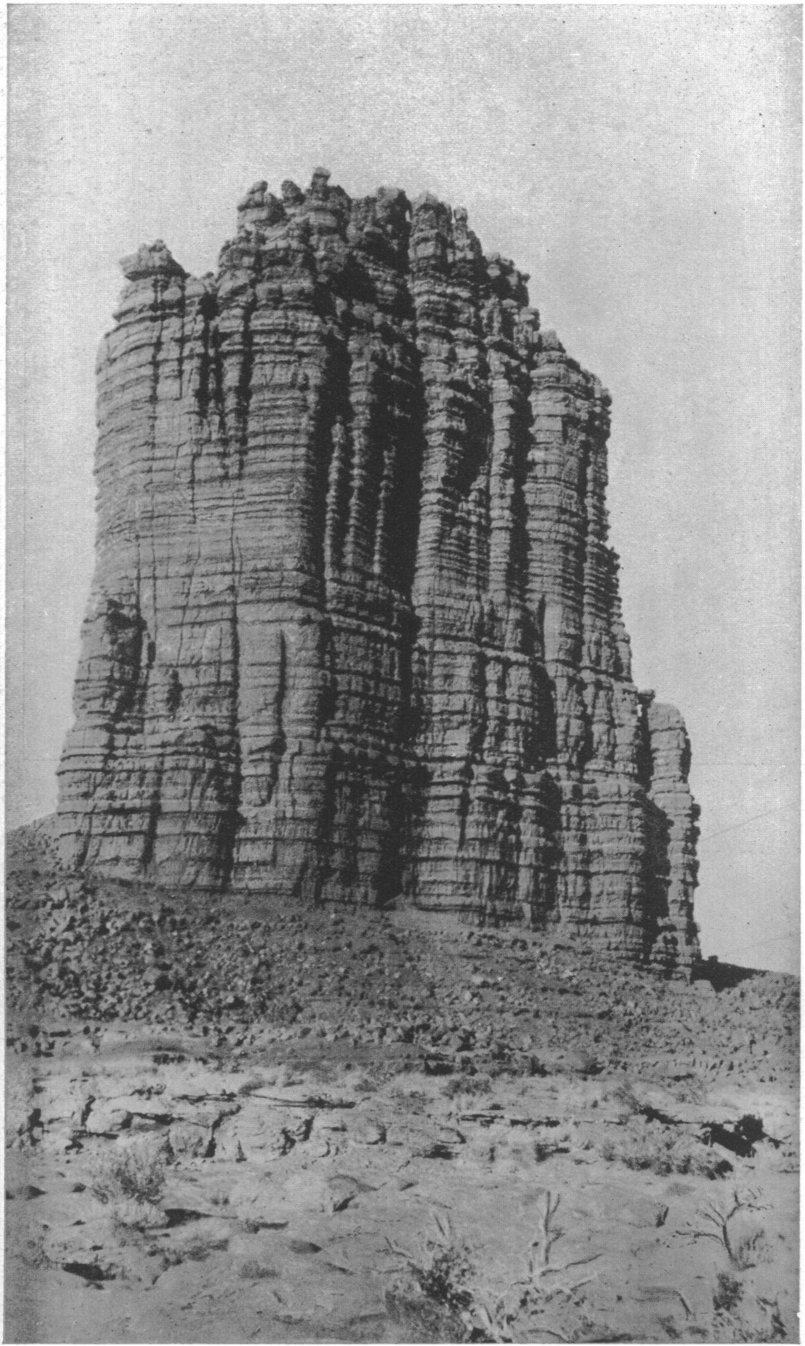

FIG. 8—Organ Rock, Moonlight Valley, Utah; an erosion remnant 400 feet in height worn from brilliantly banded shales of Permian age.

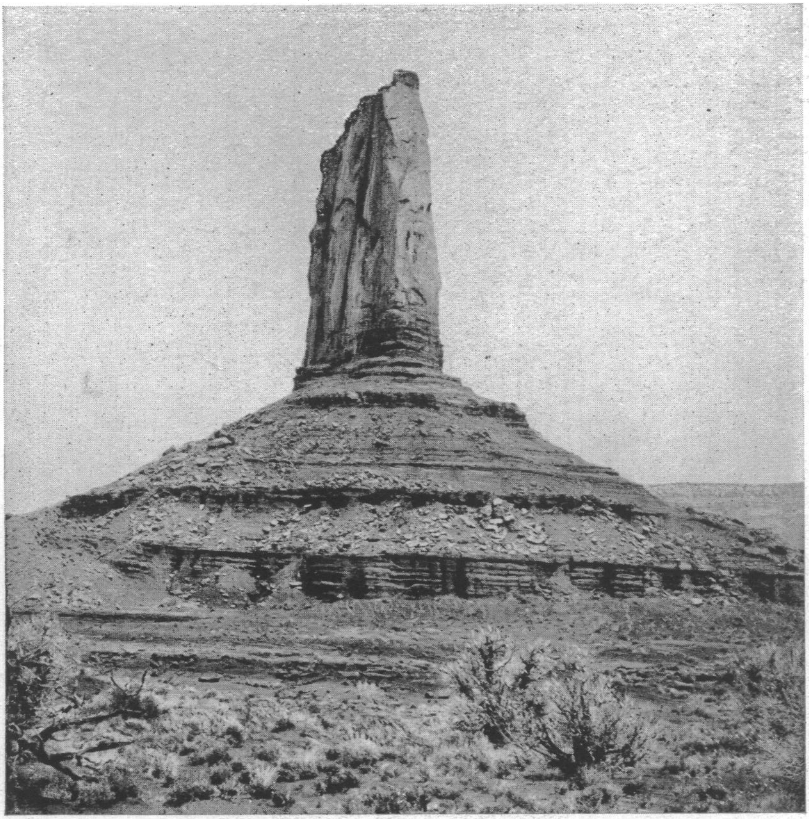

Fig. 9—Butte of massive sandstone resting on a pedestal of shale; one of a group of "monuments" in Monument Valley, Utah. The column of massive red sandstone is about 200 feet high and rests on a pedestal 300 feet high.

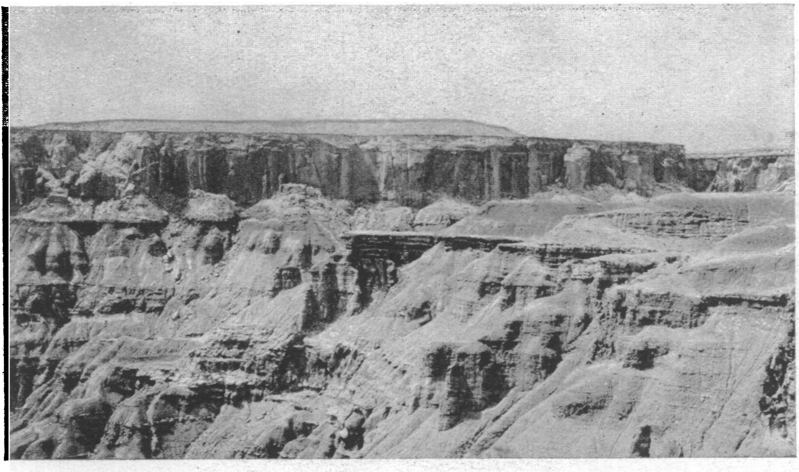

Fig. 10—Upper part of a canyon wall on the edge of Moenkopi Plateau.

All stations on the reservation record temperatures below zero and all except Fort Defiance normally experience several days each year with temperatures exceeding 100°. The daily range of temperature is over 40° and usually exceeds the difference between the means of the warmest and coldest months in the year, and consequently cool or even uncomfortably cold nights follow the heated days. In the sun the heat of summer is intense; in the shade of a rock or tree coolness prevails and unlike humid regions, the line between scorching heat and delightful temperatures is sharply drawn at the edge of a shadow.

Extensive areas of dunes and rippled flats of eolian sands widely spread over the Navajo Reservation bear witness to the activity of the wind. Rocks polished and etched by wind-blown sand, vegetation buried waist deep, and fields of corn with leaves cut into shreds are common. Sandstorms are of frequent occurrence and whirling columns of dust reaching high into the air may be counted by the dozens on clear summer days. During the larger storms the sky is darkened and the swiftly driven sand grains impel man and beast to seek shelter in some friendly arroyo. These storms are at their worst in the Little Colorado Valley, and on the Kaibito Plateau. The oasis of Tuba is walled in on the west by sand, piled against a windbreak made of trees, and the school grounds at Leupp are alternately buried and excavated. Fine sand, driven by strong winds, finds its way into the best constructed buildings. In the picturesque Navajo mythology, the Wind People were sent to dry up the earth, and ''Wind with Night'' (sand storm) is the most dreaded expression of these powers for evil.

In general the keynote of the climate of the Navajo country is variability; local climates prevail; canyon adjoining plateau, two adjoining valleys, the opposite sides of mountains and mesas, and even opposing canyon walls may have different climates. The summers are very hot; the winters are very cold; daylight is accompanied by heat, darkness by chilliness. Flood and drought appear at irregular intervals and with variable intensity. The kindly spirit who sends the gentle shower and the evil beings who remove the moisture from the air are continuously in the mind of both Navajo and Hopi.

FLORA

The early explorers were disagreeably impressed by the flora of the Navajo country. As stated by Simpson, the ''rocks are almost universally bare of vegetation except that of a sparse, dwarfish, sickening-colored aspect''; and ''cannot be regarded . . . . . .without a sensation of loathing.'' A more intimate acquaintance with the reservation brings to view a widely distributed and widely varied flora of peculiar ecologic interest which awaits the attention of botanists.

Approximately 5 per cent. of the Navajo-Hopi Reservation may properly be called ''forested'' in the sense of extensive areas of trees, chiefly yellow pine, exceeding 40 or 50 feet in height. An additional area, perhaps 20 per cent., is covered with piñon and juniper 10-20 feet in height, and numbering 100 to 200 individuals per acre; and probably one-half of the remaining 75 per cent. of the total area is marked by scattered piñon and cedar with 1-20 trees per acre. Sage, greasewood, and grass, widely variable in amount and luxuriance of growth, are found among the trees and between the bare stretches of rock and soil outside the forested area. Except in a few localities, all types of plants grow as individuals or small isolated groups; continuous sod is unknown. The total space occupied by plants is probably less than 10 per cent. of the area of the reservation, and it is possible, by taking care, to walk from Carrizo Mountain to Lees Ferry without stepping on a twig or a spear of grass.

Within the limits of the Navajo-Hopi Reservation the factor of latitude has little effect on plant life. Topography and altitude with their attendant climatic controls determine the character of the plant life and the boundaries of ecological provinces. For the region as a whole, four zones of vegetation are readily distinguished:

1. Zone of cottonwood, cactus, and yucca, altitude 3,500-5,000 feet; type area, Little Colorado Valley. Within this zone, vegetation is scanty and over large areas very inconspicuous. ''Flat-leaved'' and ''globular'' cacti are abundant, yucca is common; grass is absent or scanty and commonly in detached tufts; sage and greasewood are of small size; scrub cedar and piñon are rare. During the rainy season there is a profusion of annuals, among which Mariposa lily, yellow sun-flowers and related *compositæ* are abundantly represented. In places fields several acres in extent of yellow flowers were noted. Wild flax is fairly common.[3]

2. Zone of sage brush (*Artemisia*) and greasewood (*Sarcobatus*); altitude 5,000-6,000 feet; type locality, upper Pueblo Colorado Wash. Sage within this zone attains heights of four to five feet and, in places so closely spaced as to render travel difficult, may occupy the surface to the exclusion of trees. Besides the ever-present sage and greasewood, grass is fairly abundant in this zone. Patches of piñon and cedar are irregularly distributed, usually along rocky ridges, but are in general of ''scrub'' size (Fig. 15).

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[3] An early Spanish name for the Little Colorado River is Rio de Lino. Ives (1861) uses the term Flax River. The Navajo name is Tolchico, "red water canyon."

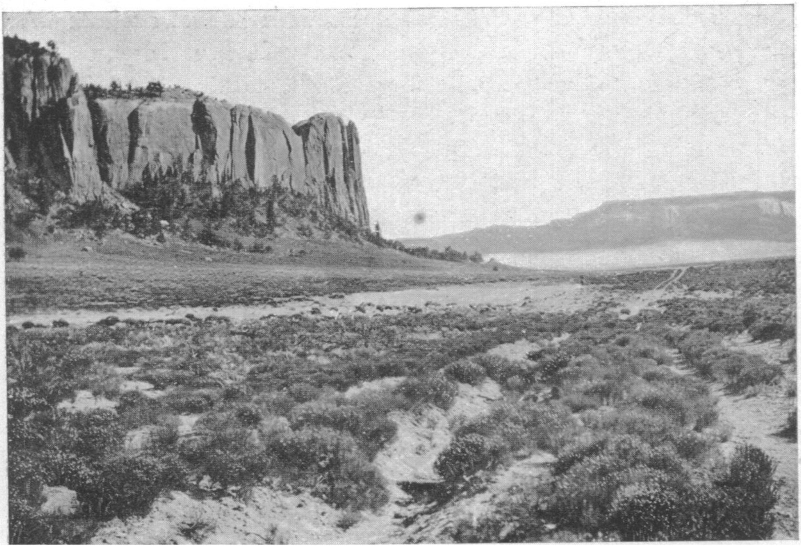

Fig. 11—Entrance to Todilto Park. The wall of massive, cross-bedded, red sandstone on the left is 220 feet high.

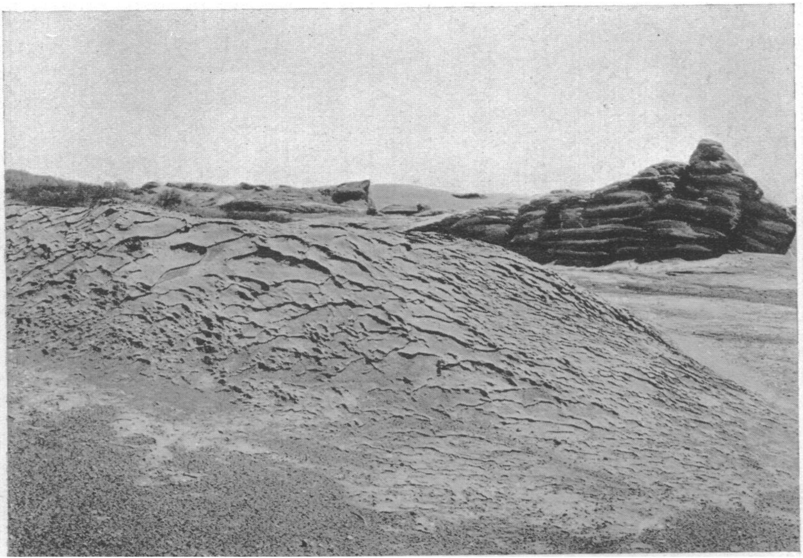

Fig. 12—Wind erosion, Kaibito Plateau. The rock is cross-bedded sandstone; wind polished and faceted pebbles are seen in the foreground.

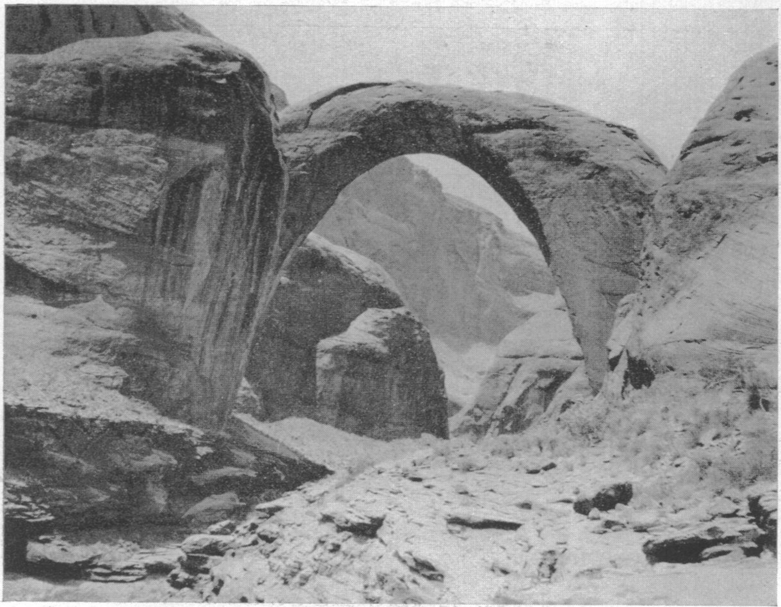

Fig. 13—The Rainbow Natural Bridge, north base of Navajo Mountain: cut from red sandstone. The bridge arch is 274 feet wide at the base and rises 308 feet above the stream in Bridge Canyon: probably first seen by white men in 1909.

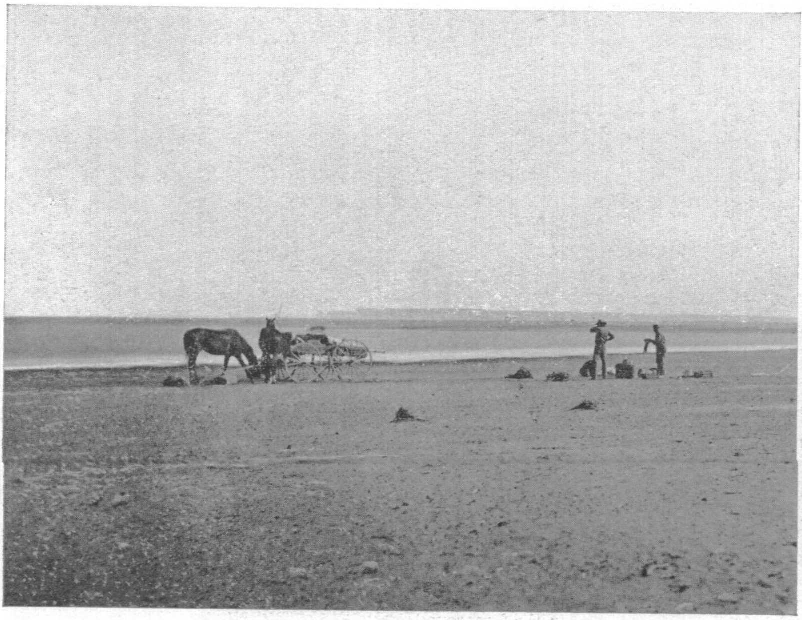

Fig. 14—Tolani (Navajo, "Many Waters") Lakes, at lower end of Oraibi Wash; one of two permanent bodies of fresh water on the Navajo Reservation below 7,000 feet.

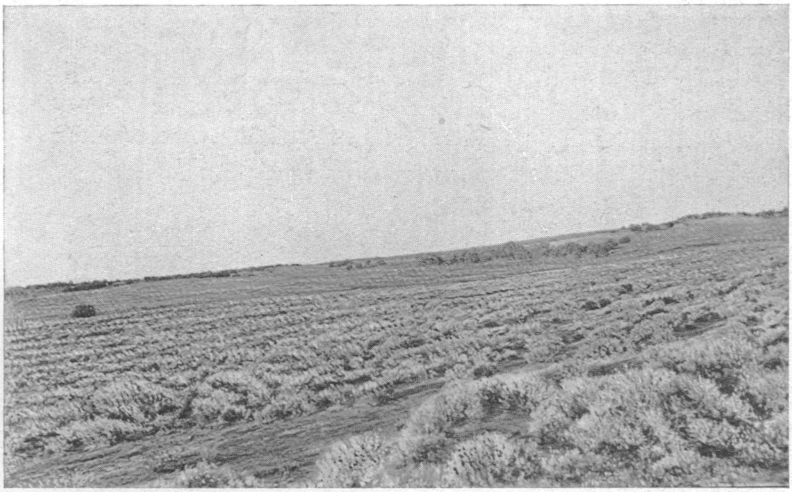

FIG. 15—Field of sagebrush with groves and individuals of piñon and cedar. Border of Pueblo Colorado Wash, elevation 5,600 feet. The sagebrush averages about four feet in height.

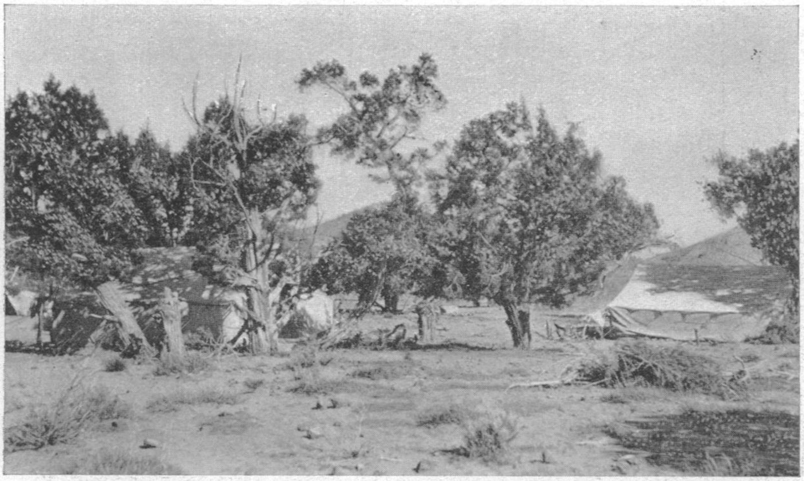

FIG. 16—Piñon and cedar in a valley among the Hopi Buttes. Elevation 6,200 feet.

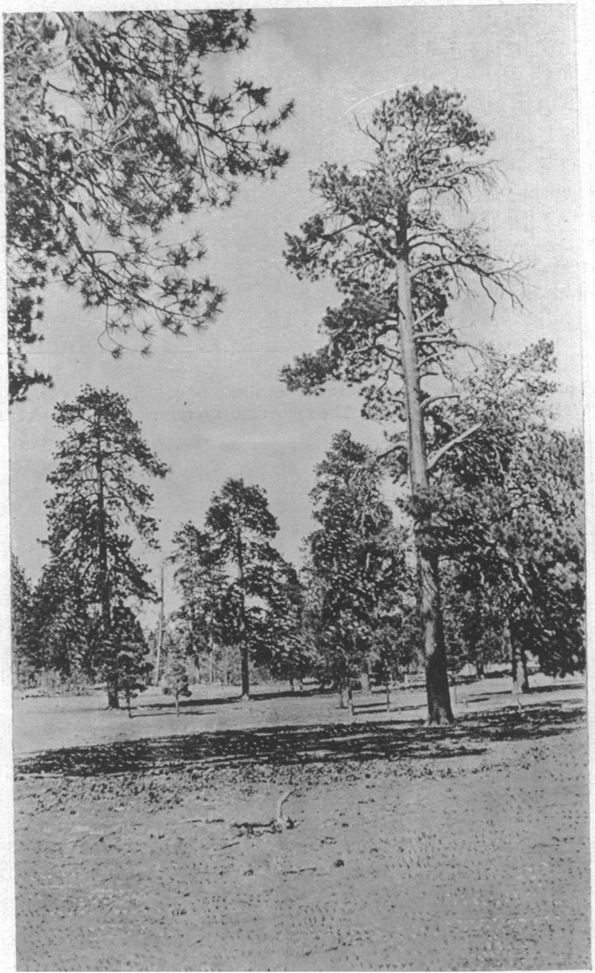

FIG. 17—Forest of yellow pine on Hubbell Plateau between St. Michaels and Ganado. Elevation 7,400 feet.

3. Zone of piñon (*Pinus edulis*) and cedar (*Juniperus monosperma*); altitude 6,000-7,000 feet, the cedar in general occurring at lower altitudes than the piñon; type locality, south edge of Black Mesa. Much of the piñon and cedar is of scrub character, but trees 12-20 inches in diameter are not uncommon and would yield 1-25 cords of firewood per acre (Fig. 16). Sage brush, and to a less extent greasewood, usually of strong growth, occupy open spaces. Groves of piñon surrounding parks of sage is the ordinary arrangement. Scrub oak and box elder are also found. Pine and a second variety of juniper (*Juniperus scopularum*) and aspen (*Populus tremuloides*) are found in a few well-watered canyons. Grass in tufts and scattered mats grows everywhere except in the densest shade.

4. Zone of yellow pine, altitude 7,000-8,500 feet; type locality, Hubbell Plateau (Fig. 17). The pines form solid forests over many square miles. The trees stand far apart and, as was long ago noted by Loew,[4] there is a singular absence of trees of intermediate heights. Engelmann spruce and Douglas spruce in groves of a few individuals are found here and there clinging to canyon walls, especially on north slopes; and white oak (*Quercus alba*) in close-set patches attains considerable prominence. Quaking aspen commonly occurs in the upper mountain valleys. Pine grass is common.

Yellow pine is practically absent from the higher parts of Black Mesa and the Tsegi Mesas at altitudes where it is to be expected. Lack of water rather than unfavorable temperature is believed[5] to account for the absence of pine at elevations between 7,000 and 7,700 feet on Black Mesa. In support of this view the presence of fir and aspen at this elevation is cited as conclusive evidence. An additional bit of evidence is the fact that, in the canyons of Tsegi Mesas and in sharp indentations on the side of Black Mesa, pines are growing vigorously.

5. Zone of Engelmann spruce; altitude 8,500-10,416 feet (the highest summits); type locality, Navajo Mountain. Outside of the type locality small groves of spruce were noted on Carrizo and the Boundary Mountains, and on Dutton Plateau. On the crest of Navajo Mountain spruce trees 12-30 inches in diameter and 70-80 feet high occur. In open spaces beneath the trees, black jack, oak, willow, ground juniper, manzanita, sage, gooseberry and raspberry attain luxuriant growths, while flowers in large variety are embedded in the grass. The profusion of flowers at moderate altitudes is remarkable for variety of species and abundance of individuals. Simpson[6] collected 90 varieties during a day's travel, and twenty-two species of plants were found in blossom on Navajo Mountain.

The boundaries of the zones roughly outlined above are subject to considerable shifting in harmony with topographic position. In general, the zone boundaries descend on the north and east, but plant societies characteristic of one zone may be found within another zone, appearing strangely out of place. Piñon represented by individuals was found in the Colorado Canyon at 3,500 feet and at 9,000 feet on Carrizo; cacti are found at all elevations and the cottonwood, abundant along the San Juan and the Little Colorado, reappears up to 6,000 feet.

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[4] Geog. and Geol. Surveys West of 100th Meridian, Vol. III, 1875, pp. 603-604.

[5] Personal communication from Mr. Don. B. Johnson of the Forest Service.

[6] P. 96 of the report of Lieut. J. H. Simpson of an expedition into the Navajo country in 1849. *Repts. of the Secretary of War, 31st Congress, 1st Session, Ex. Doc. No. 64*, pp. 55-168. Washington, D. C., 1850.

Of cultivated plants corn and cotton, probably also melons and beans, date from pre-Columbian days. The peaches at Tusayan and on the canyon floors at Nazlini, Chinle, and elsewhere were introduced by the Spaniards. Wheat was grown by the Navajos at Tsehili prior to 1849 and alfalfa at an even earlier date.

FAUNA

Previous to the Spanish invasion the inhabitants of Navajo land appear to have had no domesticated animals except the coyote-like dog. Animal food was supplied by rabbits, prairie dogs, wild turkeys, mountain sheep, and particularly antelope and black-tailed deer, which were abundant in this region until about 1875 and are still seen occasionally. The introduction of sheep and goats has greatly modified the diet of Navajo and Hopi alike, and the addition of horses, obtained first by raids on the Mexican settlements, has facilitated the evolution of the Navajo from a nomad hunter into a wandering stockman operating on an unrestricted range.

WATER SUPPLY

The Navajo Reservation is superabundantly supplied with drainage channels, but the Colorado is the only stream which maintains strong flow throughout the year. The San Juan is perennial, but its daily discharge during the summer is very small. The monthly discharge of the Little Colorado at Holbrook during spring and early summer drops to 3 to 5 second-feet, and for the 100 mile stretch below Winslow the attractive blue line of the government map should be replaced by symbols indicating ephemeral flow. Several mountain streams are perennial for short distances, but thousands of stream courses hold water only for a few hours following rains.

The average of mean annual precipitation records for nine stations within and near the Navajo Reservation is 8.29 inches, or 0.69 inches per month, an amount which, even if equally distributed, would be insufficient to maintain permanent flow, even under favorable conditions. In reality, the variation in annual rainfall at all stations is over 100 per cent.; in the Painted Desert 1,000 per cent. and evaporation amounts to about 50 inches a year. The influence of these factors taken in connection with the sparse vegetation produces great and sudden fluctuation in the volume of water carried by the streams on the Navajo-Hopi Reservation. In general, the canyons and washes are alternately flooded and nearly dry during the rainy season, and are without water during the spring and fall. In May, 1909, water to the amount of about 300 gallons per minute was flowing over Grand Falls on the Little Colorado. In June the stream was dry; by July 20 it had risen 6 feet, and attained in places the width of one-half mile. During the course of field work, July 10-21, 1913, no flowing water was found in the Little Colorado between Sunset Crossing (Winslow) and Black Knob. At noon on July 21 the water began to rise and by night had reached a stage where crossing was dangerous. During August, 1911, the Pueblo Colorado was observed to rise 13 feet in four hours; and in August, 1909, the lower Oraibi Wash, which had been dry for six months, rose during one night to a height which necessitated swimming with the horses. Following rains, the water in Tusayan, Pueblo Colorado, Wide Ruin and Chinle Washes and in Black Creek and Chuska valleys expands in places to form sheets from 100 to over 1,000 acres in extent. Frequently the rise of water is unconnected with rainfall in the vicinity.

The fluctuations in volume of stream are greatest and most sudden in the smaller channels; that the larger streams possess the same character is shown by quantitative measures on the throughflowing streams bordering the reservation. The San Juan River in January, 1905, discharged a minimum of 40 second-feet; for June of the same year a maximum flow of 24,800 second-feet was recorded. In July, 1904, this stream reached a minimum discharge of 20 second-feet, as contrasted with 20,000 second-feet in October. During the year 1906 the Little Colorado at Holbrook, where this stream is perennial, recorded a monthly maximum discharge of 3,540 second-feet and a minimum of 3 second-feet. For November, 1905, the difference between maximum and minimum flow was 20,150 second-feet. Not only is there a great difference between maximum and minimum discharge for each month, but the flow during corresponding months of different years varies from 500 to 1,500 per cent. for the San Juan. For the Little Colorado the maxima for November, 1905, and November, 1906, were respectively 20,180 and 63 second-feet, over 300 times as much in successive years.[7]

Those who are acquainted with this region retain vivid impressions of the rapid and unpredictable fluctuations of stream volume, —impressions based on experiences which involve both hardships and danger. In deep, narrow canyons the rise of water supplied by some insignificant tributary is sufficient to render the canyon impassable, a change which may come without warning and involve skillful and rapid movements to transfer one's outfit to some shelf of rock beyond the reach of the temporary flood. One season's work is sufficient to teach respect for the most innocent-looking dry channel, and to learn the wisdom of faithfully following the Navajo rule: "Always camp on the other side of the wash."

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[7] Records of stream flow obtained from various publications of the United States Geological Survey.

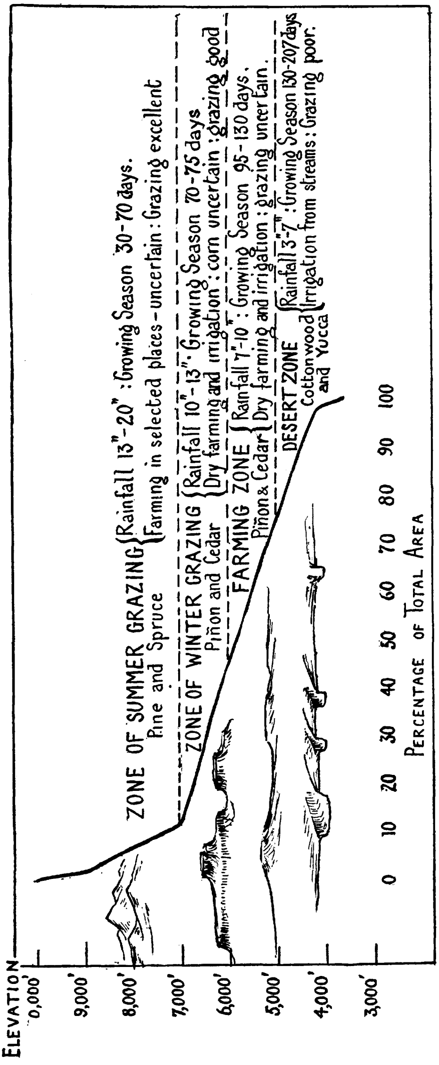
ZONE OF SUMMER GRAZING {Rainfall 13"-20" : Growing Season 30-70 days.
{Farming in selected places - uncertain : Grazing excellent
Pine and Spruce
ZONE OF WINTER GRAZING {Rainfall 10"-13" : Growing Season 70-75 days
{Dry farming and irrigation : corn uncertain : grazing good
Piñon and Cedar
FARMING ZONE {Rainfall 7"-10" : Growing Season 95-130 days.
{Dry farming and irrigation : grazing uncertain.
Piñon & Cedar
DESERT ZONE {Rainfall 3"-7" : Growing Season 130-207 days
{Irrigation from streams : Grazing poor.
Cottonwood and Yucca
0 10 20 30 40 50 60 70 80 90 100
Percentage of Total Area
Elevation
10,000'
9,000'
8,000'
7,000'
6,000'
5,000'
4,000'
3,000'

Fig. 18—Diagram summarizing the factors of elevation, topography, rainfall and vegetation as related to grazing and agriculture in the Navajo country.

The relation of variable rainfall and fluctuating stream flow to the habitability of the Navajo country is obvious. Agriculture, without irrigation except for specialized crops, is impossible. The discharge of perennial streams is sufficient for watering large tracts by stream diversion, and reservoirs are short-lived owing to the abundance of silt. As agricultural land, therefore, the reservation has small value. The needs of the stockman present an entirely different water problem: not to ensure more water where water is already sufficient, but to develop numerous small but reliable supplies where water is not now attainable. Springs must be developed and protected and wells dug until all the grazing land is brought within reach of permanent watering places. For this reason the attention of Government officials has been directed to a study of the occurrence and recovery of ground water.

SUMMARY OF PHYSICAL ENVIRONMENT

The physical factors controlling the life and occupations of the inhabitants of the Navajo country are summarized in the accompanying diagram (Fig. 18), which also indicates the conditions under which Navajos and Hopis have attained their present stage of advancement and suggests the lines along which the development of the country is most likely to be successful.

(*To be concluded*)

HAWAII'S GREAT VOLCANOES AND THE STUDY OF THEM

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Hawaiian Volcano Observatory

The Massachusetts Institute of Technology maintains an observatory at the volcano Kilauea, on Hawaii, under the direction of Professor T. A. Jaggar, Jr. This volcano is the most continuously active and one of the most easily accessible of any in the world. Only 22 miles away is the greatest volcano in the world, Mauna Loa, rising to a height of 13,675 feet, from which, at intervals of about ten years, comes a lava flow.

Kilauea is a low, broad dome, 4,000 feet in height, the top of which, over an area of three miles in length by two miles in breadth, is a depression with a depth of about 400 feet. The depression, or sink, has been flooded by flows for many centuries from the crater Halemaumau near one end of the sink, so that Halemaumau now forms a low inner dome. The Halemaumau crater is a smaller sink, in which a molten lava lake is almost continuously active. The rim of the inner pit rises to an elevation of 3,700 feet, which is about 300 feet above the lowest portion of the outer sink. The size of the inner crater and of the lake within varies with the phases of activity, but in 1915 the crater has been about 1,200 feet in diameter, and the lake within, at a depth of 365 feet or more, from 400 to 500 feet long, and 100 to 180 feet wide.

The lava lake in Halemaumau has been active from the spring of 1907 until the present time, with the exception of an interval